A Search for Candidate TeV Emitters in the High-latitude *Fermi* Unassociated Sources

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We report the results of an analysis to identify candidates for very-high-energy (VHE; E > 100 GeV) emission from the high-latitude ($|b| > 10$) unassociated sources in the year-1 catalog under development by the *Fermi* Large Area Telescope (LAT) team. These are sources with no known counterparts at other wavelengths. Since VHE instruments are pointed instruments with small fields of view and low duty cycles, their observing programs need to be planned carefully to identify the most promising targets for observation. The scientific potential of combined *Fermi* and VHE observations has already been demonstrated with a number of joint VHE-*Fermi* papers. The goal of this work is to select the most promising unassociated *Fermi* sources for joint observations with *Fermi* and the VHE instruments.

I. INTRODUCTION

The goal of this work is to find candidate very-high-energy (VHE) emitters from the sources in the *Fermi* year-1 catalogue. Many of the sources that have already been detected at VHE are in the catalog so it is already clear that *Fermi* can provide further targets of interest for VHE observatories.

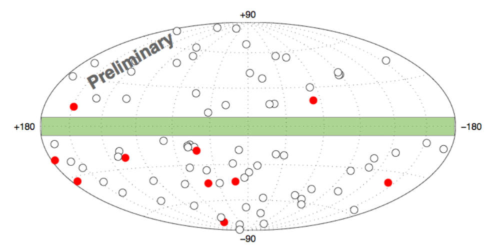

FIG. 1: Spatial distribution of the 80 candidates selected for this study in galactic coordinates. The solid red circles correspond to the top 10 candidates shown in Table I. The green-shaded region corresponds to the $\pm 10^\circ$ exclusion region centered on the galactic plane.

II. METHOLDOLOGY

A. Preliminary Scan

To begin, a preliminary scan of the catalog was performed to select unassociated sources above galactic latitudes of 10° that had potential to be VHE emitters based on their flux, spectra and redshift. Unassociated sources that met the following criteria were selected:

- $|$ Galactic Latitude $| > 10^\circ$
- Flux ($E > 100\,\mathrm{MeV}$) $> 2 \times 10^{-9}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
- Photon Index < 2.0
- Number of predicted photons > 20

This resulted in a list of 80 candidates corresponding to $\sim$11% of the total number of unassociated sources in the year-1 catalog. A skymap of these sources in galactic coordinates is shown in Figure 1.

B. Detailed Analysis

These 80 sources were then re-analyzed to search for curvature in their spectra; the sources in the catalog were all fit with power-law spectra, which gives, to first order, a good indication of their properties across the *Fermi* energy band but does not always describe accurately their spectra above 1 GeV. We included only those data at energies above 1 GeV from these sources to see if the resulting flux agrees with the power-law fit in the catalog. For each source, events were selected from a region of 10° radius centered on the catalog coordinates for that source. These data were analyzed using the standard *Fermi* analysis software (`ScienceTools v9r15p3; IRF P6_V3_DIFFUSE`) available from the HEASARC. All of the *Fermi* sources in the field of view were modeled and the background emission was modeled using a galactic diffuse emission model and an isotropic component [1]. Events were analyzed using an unbinned maximum likelihood method [2], [3].

The sources were modeled using a power law covering two overlapping energy ranges: 100 MeV - 300 GeV and 1 GeV - 300 GeV. In addition, a log parabola covering the full energy range (100 MeV - 300 GeV) was used to search for curvature. The differential flux,

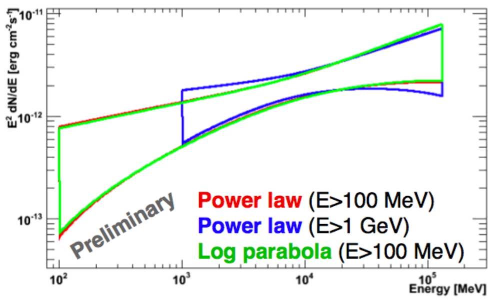

FIG. 2: SED of good TeV candidate showing no evidence for curvature in the *Fermi* energy band.

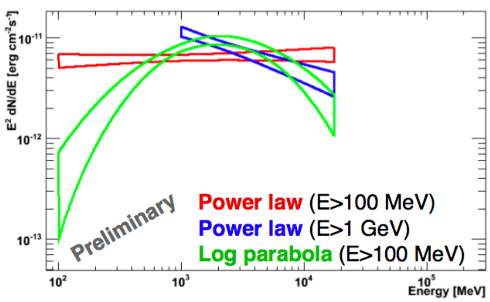

FIG. 3: SED of bad TeV candidate showing clear evidence for curvature.

$F(E)$ as a function of energy, E, for the power-law and the log-parabola spectral functions are shown in equations 1 and 2, respectively.

$$F(E) = \frac{dN}{dE} = F_0 \left(\frac{E}{E_0}\right)^{-\Gamma} \tag{1}$$

$$F(E) = \frac{dN}{dE} = F_0 \left(\frac{E}{E_b}\right)^{-(\alpha+\beta ln\left(\frac{E}{E_b}\right))} \tag{2}$$

F_0 is the differential flux at the decorrelation energy, E_0; Γ is the photon index; E_b is the break energy; α and β are the parameters of the log-parabola fit. The likelihood values of the power-law and log-parabola fits over the full energy range were compared and a χ^2 statistical test was used to calculate the probability of curvature in the photon spectrum. The covariance matrices were used to calculate the 1-sigma confidence intervals of the spectral energy distribution (SED) for each spectral model. The energy range of the SED starts at 100 MeV and terminates at the energy of the most energetic photon associated with each source. Figures 2 and 3 show SED examples for sources with and without evidence for curvature.

C. Predicting the TeV Flux

For sources where there was no evidence for curvature, the flux above 100 MeV and the spectral index obtained from the power-law fit were used to estimate the flux in the VHE band (200 GeV - 1 TeV). The *Fermi* spectrum was extrapolated to higher energies assuming no break in the spectrum and the flux was absorbed for the extragalactic background light (EBL) with the model of Franceschini et al. [4]. A redshift value of $z = 0.2$ was assumed for all sources.

For those sources where a log-parabola was a better fit, the flux and spectral index obtained using the power-law fit above 1 GeV were used for the extrapolation to the VHE band. Given that curvature was detected in the *Fermi* energy band, it is likely that the predicted TeV flux is overly optimistic. But, given the lack of knowledge about the redshift of these sources, we consider the brightest ones as good "filler" targets in under-populated RA bands. Table I lists the 10 most promising unassociated *Fermi* sources for the VHE band using our methodology.

D. Acknowledgments

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Source Name	RA (J2000)	Dec (J2000)	Fermi Flux [$E > 100$ MeV] [E-09]	Fermi Index	E$_{max}$ [GeV]	TeV Flux $10^{-12} cm^{-2} s^{-1}$	%Crab
TeV 01	00 22 22.1	-18 48 42.9	4.7 ± 1.4	1.65 ± 0.11	96	10.0	4
TeV 02	03 38 59.5	+13 12 39.7	4.1 ± 2.2	1.64 ± 0.18	133	8.91	4
TeV 03	21 18 18.4	-32 38 27.5	3.3 ± 1.7	1.61 ± 0.18	35	8.64	3
TeV 04	05 05 52.4	+61 22 32.7	4.1 ± 2.4	1.65 ± 0.18	131	8.39	3
TeV 05	13 07 40.4	-43 00 19.9	13 ± 4.1	1.84 ± 0.11	31	7.77	3
TeV 06	23 29 13.4	+37 55 29.9	6.5 ± 2.5	1.74 ± 0.13	71	7.51	3
TeV 07	04 39 53.6	-18 58 02.3	3.3 ± 1.5	1.65 ± 0.17	49	6.65	3
TeV 08	21 46 40.8	-13 45 30.3	7.9 ± 3.1	1.79 ± 0.15	52	6.60	3
TeV 09	20 14 26.0	-00 45 53.2	2.5 ± 2.2	1.65 ± 0.28	114	5.39	2
TeV 10	04 27 21.6	+20 26 06.0	2.2 ± 2.2	1.64 ± 0.29	71	4.89	2

TABLE I: Predicted fluxes in the VHE energy band (200 GeV - 1 TeV) for a the top 10 candidates for VHE emission from the *Fermi* unassociated sources in the year-1 catalog.

Department of Energy contract DE-AC03-76SF00515.

[1] http://fermi.gsfc.nasa.gov/ssc/data/access/lat/BackgroundModels.html

[2] Cash, W. 1979, ApJ, 228, 939

[3] Mattox, J.R., et al. 1996, ApJ, 461, 396

[4] Franceschini, A., Rodighiero, G., & Vaccari, M. 2008, A&A, 487, 837